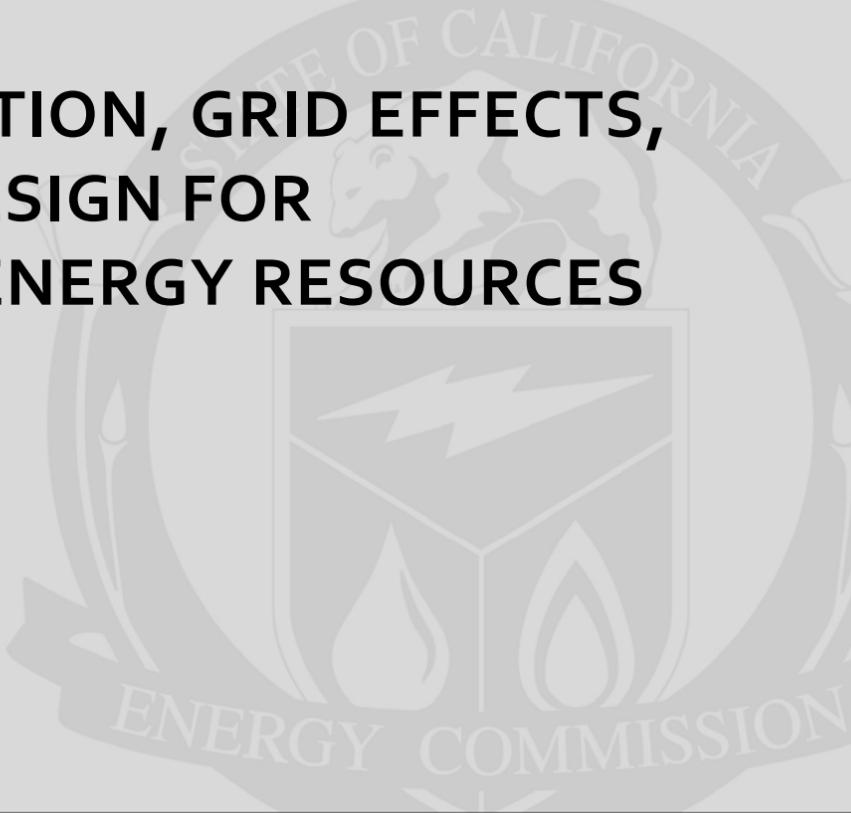


**Public Interest Energy Research (PIER) Program  
FINAL PROJECT REPORT**

**INTERCONNECTION, GRID EFFECTS,  
AND TARIFF DESIGN FOR  
DISTRIBUTED ENERGY RESOURCES**



Prepared for: California Energy Commission  
Prepared by: National Renewable Energy Laboratory

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## Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

*Interconnection, Grid Effects, and Tariff Design for Distributed Energy Resources* is the final report for the Distributed Energy Resources project 500-03-011 conducted by National Renewable Energy Laboratory. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

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For more information about the PIER Program, please visit the Energy Commission's website at [www.energy.ca.gov/research/](http://www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551

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## Abstract

The California Energy Commission Public Interest Energy Research Energy System Integration Program collaborated with the Department of Energy through the National Renewable Energy Laboratory to address distributed energy resources topics. This work focused on facilitating distributed energy resources implementation on the California and national electric power grids and included developing interconnection and power management technologies, modeling the effects of interconnecting distributed energy resources with an area electric power system, and evaluating changes to rate policies and tariffs. As a result, a technology-neutral distributed energy resources interconnection device was developed and tested, public rate policies affecting distributed energy resources were reviewed, and ratemaking policies to support deployment of distributed energy resources through public utility rates and policies were identified. In addition, a software module was developed to allow distribution engineers to model specific distribution circuits to evaluate the impact of distributed energy resources. Finally, a workshop reviewed the status and issues of advanced power electronic devices and defined the basis for an advanced power electronic interface. These advancements are expected to support the expanded use of distributed energy resources systems.

**Keywords:** California Energy Commission, Public Interest Energy Research (PIER) Program, NREL, distributed energy, power electronic interface, public policy, electricity rates, electric power tariffs, electric system model, distributed generation, fault current, interconnection, IEEE Std 1547, interface, inverter, microgrid, power electronics, power quality, energy management



# **Executive Summary**

## **Introduction**

This report summarizes the collaborative research and development conducted by the U.S. Department of Energy (U.S. DOE) and the National Renewable Energy Laboratory (NREL) and its subcontractors on behalf of the California Energy Commission Public Interest Energy Research (PIER) Energy System Integration Program to address topics related to implementing Distributed Energy Resources (DER). These technologies are important to California and the nation as additional resources for electric power. They have several benefits because they can be dispersed and either selectively placed throughout a power distribution system or region or located at or near a particular customer or group of customers. Other benefits include increased reliability and reduced transmission and distribution costs through reduced electric power system congestion and grid support, scalability to meet immediate power needs, and enhanced energy security.

## **Purpose**

Because distributed energy resources have the potential to increase the electric power resources for the state, the overall goal of this project was to collaborate on energy research with the U.S. DOE through National Renewable Energy Laboratory to develop processes, standards, and technology for integrating distributed energy resources into California's electrical distribution system and marketplace.

## **Project Objectives**

The objectives of this project are:

- Reducing the cost and time required for interconnection.
- Developing intelligent interconnection technology that promotes the distributed energy resources roles for greater energy security.
- Enhancing reliability and increased productivity.
- Proposing options for an improved regulatory and institutional environment for emerging distributed energy resources technologies.

## **Project Approach**

U.S. DOE through National Renewable Energy Laboratory collaborated with Public Interest Energy Research to conduct research in the areas listed above. To complete this work, National Renewable Energy Laboratory used competitively selected subcontractors in three topical areas, each of which addressed a specific area for implementing distributed energy research on the grid.

- Advanced Utility Interface – Northern Power Systems was contracted to develop an advanced interconnection switch to speed the deployment of distributed energy research through technical advancements and lower cost.

- Model Impacts of Distributed Energy Research on Distribution Circuit – National Renewable Energy Laboratory collaborated with Detroit Edison and Energy to develop a computer model to evaluate the effects of distributed generation on a utility distribution circuit.
- Assess National Rate and Tariff Approaches for Distributed Energy Resources – Synapse Energy Economics evaluated existing rates and tariffs.
- Develop Rate and Tariff Options for Distributed Energy Resources – National Renewable Energy Laboratory and Synapse collaborated to propose options to appropriately value both the costs and benefits of these resources.
- Status of Advanced Power Electronics – National Renewable Energy Laboratory researched the needs and requirements for an advanced power electronic interface that could be used to speed the use and acceptance of distributed energy resources in the marketplace.

### **Project Outcomes**

Project outcomes directly relate to the overall project goals.

- The project was successful in demonstrating a novel approach to interface or power switch design:
  - Northern Power developed a prototype power switch that was modeled and tested at National Renewable Energy Laboratory. The power switch met the goals set by the project, and test results showed that the prototype can be refined further.
  - There is a need for more information about the components and submodules that comprise the prototype power switch.
- Modeling tools for the Distribution Engineering Workstation (a standard power-industry tool) were developed and verified. These tools will allow utility engineers to accurately evaluate the effects of distributed generation on their particular distribution circuits.
  - Detroit Edison and DTE successfully developed and verified, through actual field implementation, models for evaluating the effects of unbalanced voltage and loads, capacitor bank use, voltage regulator control schemes, and distributed generation installation on a distribution circuit.
- Researchers identified rate and tariff options for distributed energy resources that can be applied through various regulatory bodies. These options have the potential to speed the fair implementation of distributed generation.
  - Synapse completed its survey and worked with National Renewable Energy Laboratory to develop several options for rates and tariffs that could address both the needs and the benefits of distributed energy resources on the electric power system and ultimately assist the widespread use of interconnected distributed energy resources.

- National Renewable Energy Laboratory evaluated the needs and requirements for a universal interconnection device.
  - A workshop was conducted to review the status of current technologies.
  - A draft plan was developed to implement the advanced power electronic interface concept.

## **Conclusions and Recommendations**

The project successfully achieved the objective of advancing the application of distributed energy resources in the California marketplace.

- The prototype switch met its defined goals, including satisfying the applicable provisions of the Institute of Electrical and Electronics Engineers Inc. 1547 standard. It achieved the 30 percent or greater reduction in equipment cost goal compared to current solutions and achieved a 50 percent or more reduction in project engineering costs compared to current solutions.
- Reliable analyses of the costs and benefits of on-site generation are needed to fairly implement distributed energy resources-related tariffs.
- Methods to incorporate distributed energy resources into distribution system planning need to be developed.
- Several potential tariff options could be adopted that recognize the value and benefits of distributed energy resources systems interconnected to the grid.
  - One option includes cost-of-service standby tariffs that incorporate the benefits of diversity of supply and a probability analysis to appropriately allocate facility costs among all customers.
  - Other options include providing performance incentives to customers, or implementing tariffs and policies that support state goals such as improved air quality.
- Modeled results indicate the best location for a distributed generator is most probably at the midpoint of the distribution circuit, where the distributed energy resource has the greatest impact by improving voltage profiles.
- An advanced power electronic interface is warranted to assist the distributed energy resource industry in reducing costs, improving reliability, and achieving a universal, standardized interconnection approach.

## **Benefits to California**

There are several direct benefits to California from this project.

- The Universal Interconnection prototype was demonstrated through the design of a distributed generation technology-neutral grid interconnection device that is not integrated into the distributed energy resource package. The technology-neutral switch

can be used with several distributed generation designs, demonstrating the feasibility of the universal connection approach.

- Alternative tariff and rates for distributed energy resources were developed that can be applied in California to help expand the use of distributed energy resource, achieving the benefits from adding these technologies to the electric energy supply.
- The new features of the Distribution Engineering Workstation software will enable utility protection engineers to evaluate the effects of unbalanced loading on the voltage regulation of a particular distribution circuit with interconnected distributed engineering resource systems.

## 1.0 Introduction

This report summarizes the collaborative research and development conducted by the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) and its subcontractors on behalf of the California Energy Commission Public Interest Energy Research (PIER) Energy System Integration Program. The overall goal of this project was to collaborate on energy research with the DOE through NREL to develop processes, standards, and technology for integrating distributed energy resources (DER) into California's electrical distribution system and marketplace. These activities support goals of the National Energy Policy, the California *Energy Action Plan*, and the California Distributed Generation Strategic Plan, all of which propose using DER technologies to enhance the cost-effectiveness, reliability, power quality, security, and environmental friendliness of the California and U.S. electric power systems.

NREL conducted collaborative research and contracted with three competitively selected organizations to conduct research on a range of topics. The work is reported in the topical sections that follow.

### 1.1. Background and Overview

When used in addition to centralized power plants, DER provides sources of electric power to meet the growing need for sustainable electricity supplies. The term "distributed energy resources" or "DER" includes both electric power generators and energy storage. Distributed generation (DG) includes technologies such as natural-gas turbines, photovoltaic (PV) or solar systems, wind turbines, diesel generators, machines, microturbines, and stationary fuel cells. Energy storage as an energy resource includes technologies such as flywheels and batteries. The nature of all DER systems is that they are smaller than central power plants, typically producing tens of megawatts or less, rather than the hundreds or sometimes thousands of MW associated with central power plants. Therefore the DER can be selectively placed throughout a power distribution system, dispersed throughout a region, or located at or near a particular customer or group of customers.

DER interconnected to the area electric power system (EPS) or "grid" confers several benefits. These benefits include increased reliability and reduced transmission and distribution costs through reduced electric power system congestion and grid support. DER can provide on-site power sized to meet the particular needs of a customer or customers. In addition, the typical smaller project size means the generator can be built and brought on line quickly to meet near-term needs. Therefore, using DER can allow the utility or customer to add power resources incrementally, scaled to demand growth. DER can also provide an increased degree of energy security because of the dispersed locations and potentially numerous interconnection points.

## **1.2. NREL Research and Development**

NREL collaborates with the DOE to research standards development and power electronics research and development (R&D) for interconnecting DER to the grid. NREL's engineers and researchers and its unique Distributed Energy Resources Test Facility (DERTF) were used in this work. The DERTF is designed to help the United States distributed power industry develop and test DER systems. In the DERTF, researchers use state-of-the-art laboratories and outdoor test beds to characterize the performance and reliability of DER, support standards development, and investigate emerging, often complex, system integration issues. The test facility provides capabilities that allow NREL to work closely with the distributed energy community in both the government and industry sectors to study and evaluate advanced or emerging technologies.

NREL conducted collaborative R&D on the topics of advanced interconnection interfaces, distribution circuit modeling to determine effects of DER, options for rates and tariffs to address integrating DER into the rate structure, and related research to explore the opportunities of an advanced power electronic interface.

## **1.3. Project Objectives**

The objectives of this project are to reduce the cost and time required for interconnection, develop intelligent interconnection technology that facilitates the DER roles for greater energy security, enhanced reliability, and increased productivity, and to propose options for an improved regulatory and institutional environment for emerging DER technologies.

## **1.4. Report Organization**

This report is organized to discuss each of four tasks conducted by NREL and its subcontracted research. The three final reports from the subcontracted research are included as Appendices.

## **2.0 Project Approach**

NREL conducted collaborative R&D with three subcontractors. The three companies were Northern Power Systems, Detroit Edison, and Synapse Energy Economics. NREL consulted with the each subcontractor to assist in defining the approach, key methods, and testing and evaluation of the prototype developed as part of this work.

## 3.0 Project Results

Each of the four tasks conducted in this project are summarized in the following sections by topic.

### 3.1. Universal Interconnect Device

#### 3.1.1. *Universal Interconnect Purpose and Approach*

Interconnection equipment between distributed energy resources (DER) and the grid have been custom-designed by the DG manufacturer or integrated by engineering firms using subcomponents such as relays, sensors, and switchgear. The purpose of this task was to develop a prototype switch to model a grid interconnection device with built-in flexibility to manage a range of distributed generators. Northern Power Systems (NPS) was competitively selected to develop the utility interconnection device. NREL collaborated on the switch development, modeled the interface, developed test procedures, and performed the testing. NREL evaluated the performance of the prototype switch to meet specific requirements. The objective was to create a standard, flexible universal interface switch for DER so single or multiple DER systems, such as wind turbines or solar arrays, can be readily and inexpensively connected to a utility.

Target performance characteristics and prototype requirements were that the switch integrate all the required equipment for the DER interconnection into a single package and be designed to be compliant with IEEE 1547 and UL 1741 standards. NPS designed, built, and tested a 480V, 200A, fully functional circuit-breaker-based prototype with a digital signal processing (DSP) board. After testing at NPS, the switch was shipped to NREL's DERTF. The resulting interconnection switch design is DER-technology neutral and can be used for inverter and machine distributed generator applications. NPS created three switch designs: 1) a circuit breaker design, 2) a silicon-controlled rectifier (SCR) design, and 3) an integrated gate bipolar transistor (IGBT) design. The circuit breaker design was selected to meet the program's schedule and budget. The circuit breaker-based DER switch is compliant with IEEE 1547. In tests and modeling, it is obvious that the circuit breaker is the limiting factor for switching speed in the prototype DER switch. Faster switching speeds are possible by incorporating either the SCR or IGBT technologies, as it is estimated that the DSP board is responding within a sub-milliseconds time frame. While the accuracy of this prototype, using a circuit breaker-based DER switch, was estimated at 5%, greater accuracies are possible. This switch option was a lower-cost, rapid prototype design that can be modified to adapt it to a wide range of requirements and a large number of applications.

#### 3.1.2. *Universal Interconnect Goals*

The goal of this project was to develop a DER interface system with features and functionality not currently available to the market. Design and performance specifications were planned in order to streamline the engineering and approval process for interconnecting DER assets to the

utility Specifications were also planned to add functionality that enhances the value of the DER to both the utility and the local power consumer. Specific technical and economic goals were:

- Compliance with applicable provisions of the IEEE 1547 standard.
- 30% or more reduction in equipment costs compared to current solutions.
- 50% or more reduction in project engineering costs compared to current solutions.
- Mean time to failure (MTTF) in excess of 80,000 hours.
- Mean time to repair (MTTR) less than two hours.
- Implementation and demonstration of effective anti-islanding methods for both conventional and power converter based DER systems.
- Implementation and demonstration of resynchronization methods for both conventional and power converter based DER systems.
- Fully functional and demonstrated energy enterprise management interface.

### **3.1.3. Universal Interconnect Results**

This section describes the equipment specifications and how the prototype switch achieved the planned goals. NREL participated in the evaluation of the prototype, and many of the tests were conducted at the NREL DERTF. Results are summarized here.

NPS designed and built a prototype flexible interface with a complete interconnection package. This prototype was evaluated according to the goals. In Figure 1 the switch is shown open to illustrate the switch layout. Figure 2 is a photo of the NPS flexible interface prototype in its normal operating configuration ready to be tested at the NREL DERTF.



**Figure 1. Profile of flexible DER switch**

Photo Credit: NREL



**Figure 2. Northern Power prototype switch at NREL for testing**

Photo Credit: NREL

The NPS Flexible Interface prototype includes a number of features, as listed below:

- Complete interconnection package, including: circuit breaker (in lieu of solid state switch to reduce testing costs), relay functions, communication interface, sensing current transformers, potential transformers, and digital signal processor (DSP) control.
- Full dual-source sensing with advanced control, monitoring, and diagnostics algorithms.
- High bandwidth measurement incorporating full DSP capability.
- Remote current measurements with anti-islanding with zero non-detect zone.

System features are listed in Table 1.

**Table 1. Northern Power Systems switch system features**

<b>System Features</b>	
High speed grid disconnection	Integrated power quality and monitoring functions
Integrated switchgear control	Backup trip of input circuit breaker
Integrated protective relaying	Switch position indicator
Integrated anti-islanding function using reverse power trip	

Utility specifications are summarized in Table 2.

**Table 2. Switch specifications for utility applications**

<b>Utility Specifications</b>	
Nominal output voltage	480 Vrms
Output voltage range	+10, -15%
Frequency range	45 to 65 Hz
Output configuration	3 phase, 4 wire
Rated output current	200 Amps
Surge output current	400 Amps for 10s
Target detection time	< 2 ms
Target clearing time	<0.1 ms for IGBT, <100ms for CB

The prototype also had cost goals, and NPS reports that the prototype met these goals, as illustrated in Table 3.

**Table 3. Comparison of costs and switch technology**

<b>Technology</b>	<b>Material Cost</b>	<b>With NRE* &amp; Spares</b>
Circuit breaker design	\$10,503	\$16,200
Silicon controlled rectifier design	\$20,208	\$47,300
Integrated gate bipolar transistor design	\$23,366	\$61,300
Total cost goal	30% less than current practice	Not defined

\*NRE=Non-recurring engineering costs

For the CB design, MTTF was 256,000 hours, for the SCR it was 60,000 hours, and for the IGBT design it was 55,000 hours. The MTTR was less than two hours based upon the calculations from parts selection and design. In summary, the CB switch leads to the lowest cost; the IGBT-based prototype switch requires a substantial amount of non-recurring engineering (NRE) time and spare parts, which are expensive. The cost of the SCR switch is lower than the IGBT switch and it also has lower conduction losses. Although the cost of components for the IGBT-based switch is twice the cost of CB-based switch, when the future benefits of this technology are factored into the analysis, power quality benefits can make the IGBT-based switch a more promising solution.

The switch demonstrated effective anti-islanding methods for both conventional and power-converter based DER systems. The IEEE 1547 standard requires that the switch disconnects from the connection within two seconds. Sample data are summarized below (Table 4) and demonstrate how the unit meets the IEEE 1547 specifications.

**Table 4. Switch Disconnection Test Results**

<b>Trial #</b>	<b>Trip Time (sec)</b>
1	0.093
2	0.0945
3	0.096
4	0.0954
5	0.097

Source: NREL

Resynchronization methods were demonstrated for both conventional and power-converter-based DER systems. The synchronization function includes user adjustable settings for the voltage, frequency, and phase windows, and occurred faster with a larger phase window.

Researchers demonstrated a fully functional energy enterprise management interface. NPS uses its proprietary Smartview® package, which includes fleet and local monitoring of geographically distributed units, a flexible graphical interface, real-time data and alarms, historical data, supervisory controls, automated alarms reported via email and pager, and automated data reporting.

### **3.1.4. NREL Testing of the Universal Interconnect Switch**

Testing that required more advanced and precise capabilities was performed at NREL's DERTF by NREL staff. All tests were performed under the general guidelines set forth in the standard IEEE 1547.1 "Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems." All protective relay functions were tested to the values prescribed in IEEE 1547 "Standard for Interconnecting Distributed Resources with Electric Power Systems."

The following protection functions were satisfactorily tested:

- Under voltage
- Over voltage
- Under frequency
- Over frequency
- Synch check
- Directional power for both reverse power and anti-islanding functions
- Re-closing

- Power quality adherence to the CEBEMA curves

NREL also tested the calibration and accuracy of an NPS digital signal processor controller. In this application, the controller was used to operate a circuit breaker switch for DER interconnection with a microgrid. NREL found the device met expectations, but needed improvements in calibration and measurement accuracy for utility interconnection.

### **3.1.5. Universal Interface Conclusions**

Through the universal interface, a range of requirements for grid interconnection of DG equipment was surveyed. The results of this survey led to the design of a grid interconnection device that is technology neutral and not integrated into the DER package. The specification of the DER switch was based on past NPS project experience. Such a switch is cost-effective in low voltage applications at a current rating greater than 200A. Preliminary designs were developed for both electromechanical- and semiconductor-based DER switches. Use of a semiconductor-based switch makes it possible to meet requirements for fast disconnection and power quality requirements such as CBEMA. Such a high performance switch would have a higher cost.

A prototype switch was constructed using CB technology to keep prototype cost low. NPS and NREL completed a detailed test program to verify the protective relay functions and IEEE1547 functions implemented in the switch controller. The test results indicate a successful system and control architecture for the DER switch.

Studies conducted during the DER switch program indicate unique advantages for a grid interconnection device using semiconductor-based switches, especially for use in network grids. Such a high-speed switch can also be used to meet higher power quality goals for loads connected to the DG.

NPS and NREL performed extensive testing to validate the performance of the switch. This testing included the performance and operation of the control algorithms, relaying, IEEE 1547 specifications, and power quality functions. Specific assessments tested detection, over and under voltage, over and under frequency, phase sequence, reverse power, instantaneous and time over current, discrete event trip, unintentional islanding, reconnection, open phase, and three phases. NPS and NREL found that the DER switch met these requirements.

In summary, the prototype switch met its defined goals, including meeting the applicable provisions of the IEEE 1547 standard, achieving a 30% or more reduction in equipment costs compared to current solutions, and achieving a 50% or more reduction in project engineering costs compared to current solutions.

## **3.2. Innovative Ratemaking Treatment for DER**

### **3.2.1. DER Ratemaking Purpose and Approach**

The purpose for this research was to develop innovative concepts and methods for ratemaking treatment of DER interconnected with the grid. The focus of this effort was to explore ratemaking methods that are compatible with, and complementary to, more sophisticated approaches to integrating DER into distribution systems and electricity markets.

New approaches to ratemaking are essential at this point in the transformation of the electric power systems and markets. The improvements in technology and power system innovation now require corresponding regulatory innovation. This project's goal was to provide a foundation for California policy making, thereby helping California, utilities, and other interested parties to build upon the assessment of current actions and recommendations from the research team.

To accomplish this task, NREL negotiated an agreement, "Rate Structures for Customers with On-Site Generation: Practice and Innovation," with Synapse Energy Economics. This agreement required Synapse to conduct an assessment of current ratemaking practices. Using this foundation of interviews and evaluation of rate cases and ruling, both Synapse and NREL developed recommendations for additional rate policies and tariff options.

### **3.2.2. DER Ratemaking Discussion**

During the late 1990s, state and federal policy makers began to address the challenges that were preventing DER from becoming an integral part of the traditional transmission and distribution grid. There have been significant increases in DER installations in the past decade, but there are ample opportunities for expanded applications.

One characteristic of customers with onsite generation is they typically choose to remain connected with the area EPS or grid to meet electrical needs exceeding the capacity of their DER system's capacity. Interconnection also ensures the reliability of their electric service. Grid electricity to these customers has been characterized as standby, backup, scheduled maintenance, and supplemental power. Therefore, those who incorporate DER into their energy plans are also subject to the regulatory structure, and an examination of rates and tariffs affecting the DER was warranted.

Before determining options for treating interconnected DER, researchers needed to examine the existing regulatory environment. Both the rate components used and the requirements relating to interconnected DER were surveyed. To ensure a cross section of information, the states selected for the survey varied in both geographical location and in the structure of their electric industries. The 10 states selected are proactive in regulating DER rate policies and include: Arizona, California, Indiana, Massachusetts, Minnesota, New York, Oregon, Rhode Island, Texas, and Vermont. Synapse also interviewed 30 key personnel in various organizations and companies with a professional interest in the issue, e.g. public utility commission staff, DER developers, engine manufacturers, utility officials, trade organization representatives, advocates, consultants, and other experts.

Survey findings noted that there are various rate components:

- Standby and related rates, including customer-related charges (e.g. billing and metering).
- Demand charges for capacity.
- Distribution costs, energy charges.

- Miscellaneous cost adjustments – “risk” or “system usage” fees such as interconnection fees, standby (or backup) charges, demand and energy rates, and estimates of allocated costs (either marginal and embedded).
- Potential utility stranded costs.

In addition, the survey found that some states allow various exemptions for DER systems, such as exemptions for renewables-based systems or systems that will improve the air quality in a specific area or to meet overall quality targets. Some states also tie the customer’s demand charge to their peak usage.

At the time the survey was concluded in the fall of 2005, no state had conducted cost-of-service studies solely for purpose of determining the costs for distribution.

### **3.2.3. DER Conclusions and Recommendations**

Through reviews of regulatory proceedings, existing tariffs, publications, and interviews, the researchers identified a number of approaches to standby and associated rates that deserve policy makers’ attention if they are to promote cost-effective DER deployment. For example, implementing DER reduces consumer demand for grid-supplied energy and DER systems can defer or avoid transmission and distribution investments. However, it is also important that all customers pay their share of the costs for the availability and reliability of grid power. It is apparent from the survey that in order to fairly implement DER-related tariffs, reliable analyses of the costs and benefits of on-site generation are needed. At the time of this survey, no such evaluation had been conducted. Analyses and modeling also need to be done to examine the effects of DER system on distribution systems. (Note: Part of this question has been addressed, see Section 3.3, below.)

There are several potential tariff options regulatory agencies could adopt to recognize the value and benefits of DER systems interconnected to the grid. One option is that standby tariffs could be implemented that are formulated to be cost-based and DER-specific. These “cost-of-service” standby tariffs need to include the benefits of diversity of supply and a probability analysis in order to appropriately allocate facility costs among all customers. Another tariff option could be to provide performance incentives to customers. And finally, regulatory commissions and utilities need the capability to incorporate DER into distribution system planning and need methods for valuing DER.

There is an opportunity for a cost-based tariff option. Allocating distribution costs based on maximum demand gives value to an intrinsic DER benefit, which is that the DER system owner can choose when to use the grid. By choosing to reduce standby demand or to produce electric power for the grid during peak demand, this benefit could reduce the costs otherwise allocable to DER, or any other customers, willing and able to modify the timing of their peak demand.

### **3.3. Modeling and Testing of Effects of Unbalanced Loading in Voltage Regulation**

#### ***3.3.1. Distribution Circuit Modeling Purpose and Approach***

As noted in Section 3.2, three analyses and modeling are needed to examine the effects of DER systems on the electric distribution system. NREL contracted with Detroit Edison, which was competitively selected for this work, to develop and verify load models and distribution circuit models. Detroit Edison developed and verified these models using the Distribution Engineering Workstation (DEW) software, which has powerful capabilities for modeling distribution circuits.

This project consisted of three major parts:

- Develop and adapt the DEW software to determine the voltage profile on a selected distribution circuit under different operating conditions.
- Determine the voltage profile with DER operating on this circuit.
- Measure the voltage profile throughout the circuit.

#### ***3.3.2. Distribution Circuit Modeling and Testing Results***

The impacts of DER on a distribution circuit need to be evaluated because circuit design and operation can allow two-way power flows when DER is interconnected to the grid. This results in imbalances and unsafe operating conditions. At the time this research had begun, the analytical tools were primarily based on an analysis assuming a balanced three-phase operation. In actual operation, most distribution circuits are single-phase, and therefore less accurate. The research conducted under this task developed accurate models as verified on an actual circuit, allowing the utility to precisely determine the effects of DER systems on a distribution circuit.

Prior to starting on the model, Detroit Edison and its lower-tier subcontractor, DTE Energy, surveyed 13 utilities to determine their average voltage imbalance conditions. These values were used to assess the model to ensure that the values incorporated in the model were typical for the industry.

Detroit Edison and DTE Engineering selected the Milford distribution circuit that already had a DER system installed to reduce overload and improve voltage regulation. Using the open access DEW software the team developed models and ran simulations to calculate voltage profiles. Detroit Edison installed monitoring equipment throughout its test distribution circuit so that performance data could be collected at several points on the distribution circuit. These actual

data were then compared with the modeled data to assess the value of the modeled results, and the model was updated as needed.

- Multi-grounded three-phase wye system
- Loads: 76% residential, 4% commercial, 20% light industry
- 31,000 feet (5.9 miles) circuit
- Summer peak = 15.3 MVA
- Annual load factor = 0.42
- Installed DER (1 MW synchronous generator).



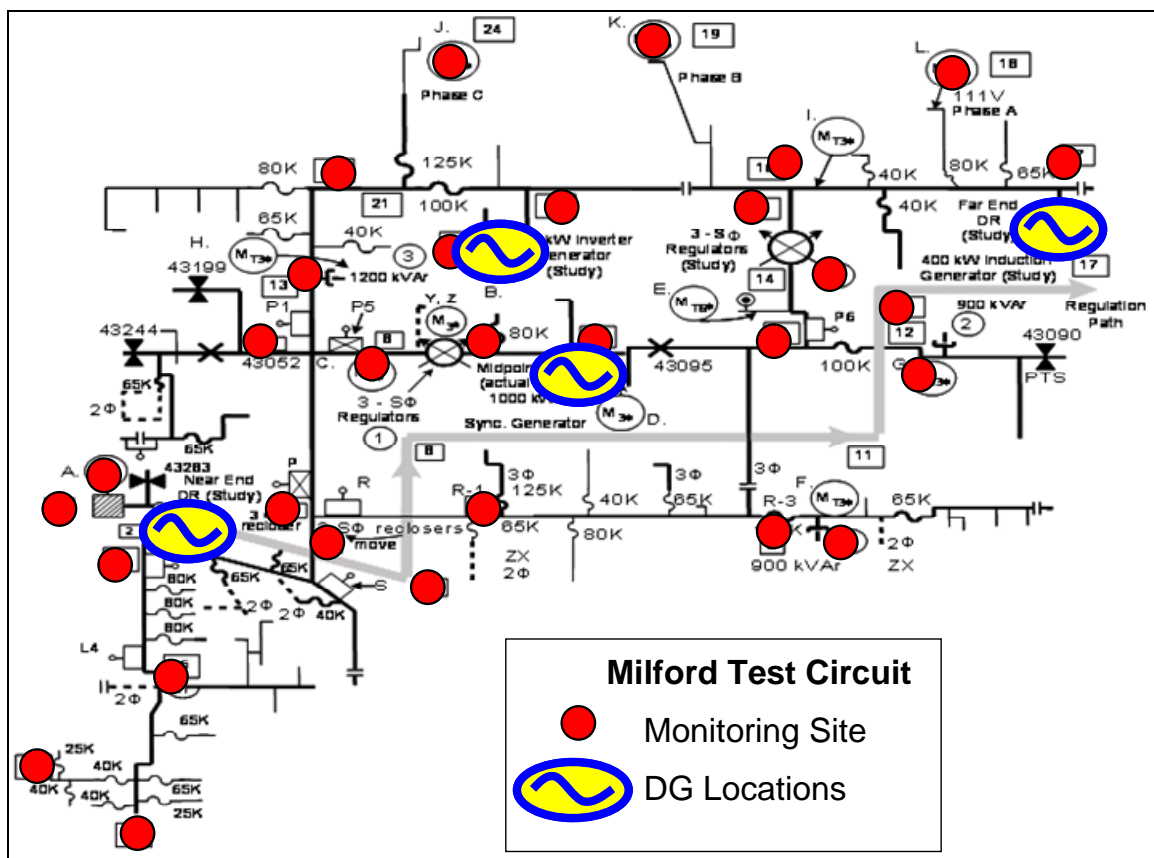
Photo Credit: NREL



**Figure 4. Example of additional monitoring node on distribution circuit**

Photo credit: NREL

The line drawing of the distribution circuit is included in Figure 5.



**Figure 5. Milford distribution circuit diagram illustrating DG land monitoring locations**

Source: NREL

As part of this evaluation, the Detroit Edison team conducted a survey to identify and catalog the traditional voltage regulation methods. The team then defined unbalanced voltage and unbalanced load effects on system protection. Team members studied and reported on the effects of unbalanced voltage and unbalanced load on sensitive ground relaying on the modeled circuit and determined the adequate protective relaying limits for different levels of unbalance and for DER systems. These studies included a 1 MW synchronous generator located at the midpoint on the circuit and simulations for a 400 kW high-speed generator and inverter, a 400 kW self-excited induction generator, and a 1 MW synchronous generator near the end of the circuit. Voltage regulation models were developed for the transformer at the substation, the bi-directional voltage regulators, the capacitors, all the distribution circuit transformer connections, and the line sections. In addition, models for synchronous-, induction-, and inverter-type generators were defined, and appropriate voltage regulation models were then developed.

The voltage profiles were simulated to determine the circuit voltage profiles on the Milford distribution circuit under different loading conditions. This circuit was modeled based on unbalanced conditions, including line voltage drop, line losses, and secondary and service real losses. The three DER were then modeled to determine the effect on the distribution circuit voltage regulation by varying the magnitude of the real power injection and the reactive power (export or import). The team evaluated data collected from the Milford circuit to test the model and voltage regulation capabilities for the three DER systems.

### ***3.3.3. Distribution Circuit Modeling and Testing Conclusions and Recommendations***

This research developed and validated DEW modeling tools that will enable utility protection engineers to evaluate the effects of unbalanced loading and various voltage regulation methods for a distribution circuit with operating and shutdown interconnected DER systems.

The DEW software was expanded, and the models validated using an instrumented, real world distribution circuit with interconnected DER systems. Results from the verified models indicated that the best results are obtained using the voltage-dependent current module to represent how the circuit load changes with changes in source voltages. The more typically applied constant power model was the worst for predicting behavior, with an average 12.5% variance compared to actual measurements. The models indicated that for a distribution circuit, the optimum location for the maximum released capacity is at the substation. To alleviate losses, the optimum location of the DER system is at the end point of the circuit, though this is only slightly better than when the DER is located at the midpoint. However, the optimal place to locate a DER system to achieve the best voltage regulation on a distribution circuit is at the midpoint of the circuit.

Recommendations from this study are that system engineers conduct a three-phase unbalanced power flow study, as the balanced model is inaccurate. The DER system should be modeled at the locations where the installations are planned. To use the models and obtain accurate results, the only measurements needed are the phase voltages and current taken at the source, regulators, capacitors, and DER system locations.

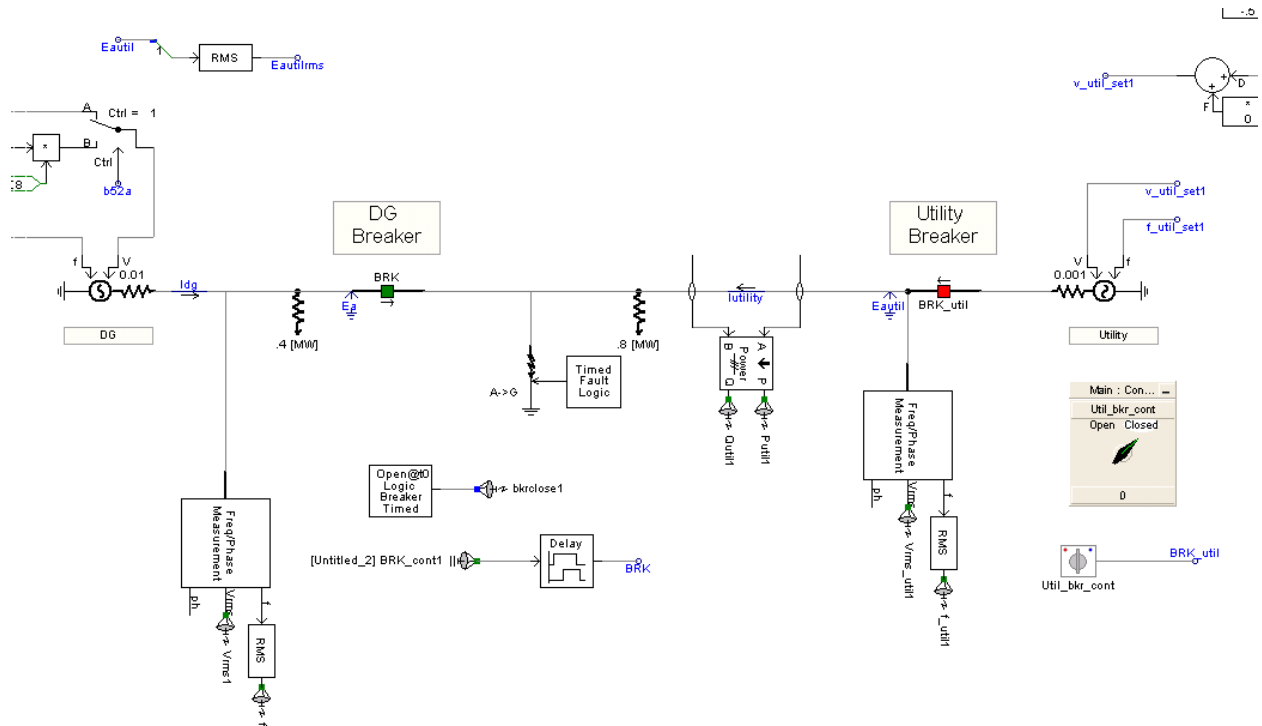
### **3.4. Modeling, Research, Analysis, and Planning**

This task conducted modeling, research, analysis, and planning for Distributed Energy Resources System Integration, Interconnection, and Operation with Electric Power Systems. Topics included advanced electronic interfaces, evaluation of interconnection devices, and issues related to power quality, reliability, modeling DER equipment and systems, and research and analysis of interconnection issues. The research analysis, modeling, and technical review were conducted in two subtopic areas. These topics and their findings are described in the following sections.

#### **3.4.1. Subtask 1 – Modeling and Validation**

Reliable models are needed for widespread acceptance, to facilitate permitting, and for ease in selecting DER applications. As part of the work to develop and evaluate reliable models, NREL developed a model for the Northern Power Universal Interconnect Switch. NREL developed and validated the model to reliably predict the performance of the switch with the grid. Because modeling will be an essential tool in the future analysis of grid-tied DER applications, researchers need to develop models that can reliably predict the behavior of DER and the interconnection device for a wide range of applications and power scenarios. A model of the NPS DER switch was developed as part of this project to predict and understand the performance of the Northern Power Flexible Utility Interconnection Device with the grid. Modeling is an essential tool in the analysis of grid-tied DER applications, and as such, there will be substantial benefits to be realized from models that can reliably predict the behavior of DER interconnection devices for a wide range of applications and power scenarios. This model will prove beneficial to not only the NPS switch, but to upcoming utility interconnect technologies as well.

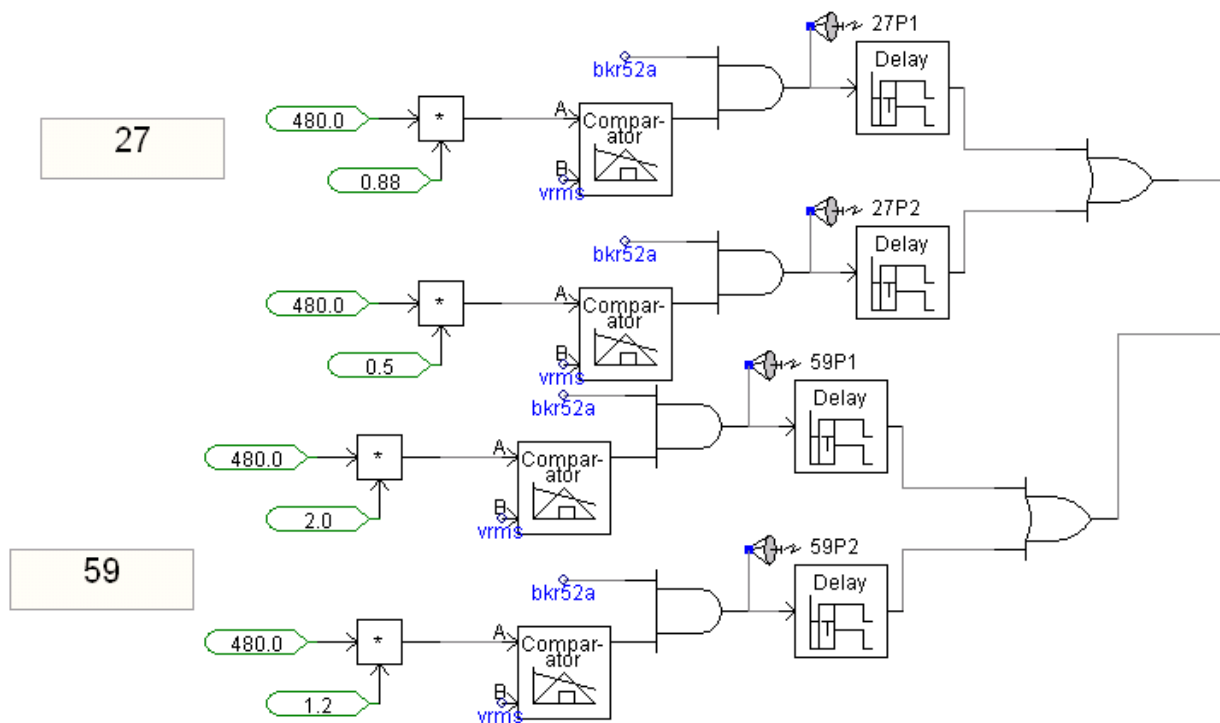
The protective functions of the DER switch were modeled using the power systems modeling program PSCAD. The model is defined by a simple system consisting of two paralleled generators connected by a breaker (Figure 6). The breaker, which simulates the DER switch, is operated by a system of logic controllers that provide trip signals or allow closing based on line conditions. The parallel sources have independently controllable frequency and voltage. These parameters are adjusted to simulate line fault conditions and to test the validity of the logic controllers.



**Figure 6. Model of the Northern Power switch**

Source: NREL

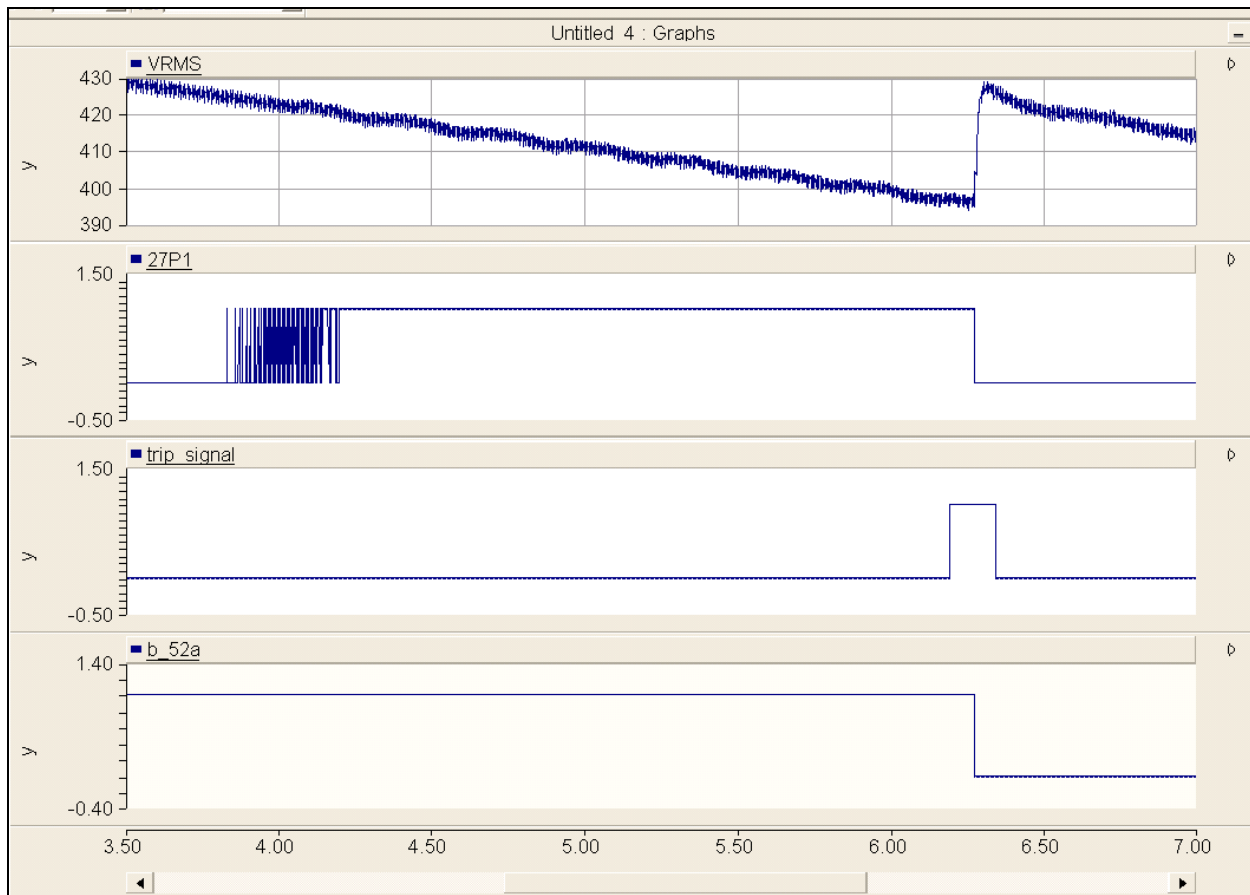
Researchers conducted validation trials by altering model parameters to cause faulted conditions. The protective functions of the DER switch were modeled using the power systems modeling program PSCAD. The model is defined by a simple system consisting of two paralleled generators connected by a breaker (Figure 7 below). The breaker, which simulates the DER switch, is operated by a system of logic controllers that provide trip signals or allow closing based on line conditions. The parallel sources have independently controllable frequency and voltage. These parameters are adjusted to simulate line fault conditions and to test the validity of the logic controllers.



**Figure 7. Example logic controllers from the model for under- and over-voltage trip functions**

Source: NREL

The 88% under-voltage function is an example logic controller and is the top row of logic in Figure 7. The trip setting and sensed line voltage are provided to a comparator block through inputs A and B, respectively. The comparator block determines if the sensed line voltage is less than the setting. If it is, the comparator outputs a logical "1" to an "and" gate. If the breaker is closed, the second input into the "and" gate is also "1." This results in a logical "1" input to a delay timer, which, if the conditions persist for the set time delay, outputs a signal to trip the breaker. These results are illustrated in Figure 8.



**Figure 8. Example, 88% under-voltage, time delay: 2 seconds**

Source: NREL

Trials modified the generator settings to cause faulted conditions. To test the under- and over-voltage and frequency settings, the parameter being tested was adjusted while the breaker was closed until the setting was exceeded, at which time the breaker tripped.

By design, the model performed as desired. This model will provide a backbone for future advanced switch design testing. Capabilities, such as semiconductor-based switching, can be incorporated into future systems to aid algorithm design and validation testing of more advanced utility interconnection devices.

### **3.4.2. Research and Analysis Purpose and Approach**

The purpose of this work was to evaluate the needs and availability of an advanced power electronics interface (APEI) for DER. NREL's approach was to review the available technologies and conduct a technical workshop to assess the technology gaps and identify the research needed to establish advanced power electronic interface technology to support reliable, durable, grid-interconnected DER for California.

#### **Interconnection Technology Gap Analysis**

NREL conducted a "gap analysis" of the technologies for interconnecting DER to the grid. This work indicated that by taking advantage of technological innovations in semiconductor

materials, power electronics researchers are creating devices that enhance energy generation and delivery systems. The versatility and reliability of lower-cost devices combined with advancements in circuit topologies and controls has resulted in technologies that replace what was traditionally done by electromagnetic and electromechanical systems. With the development of solid-state-based packages, power electronic devices can now convert almost any form of electrical energy to a more desirable and usable form.

Another benefit of power electronics is their extremely fast response times. Power electronic interfaces can respond to power quality events or fault conditions within one-fourth of a cycle. This high-speed response can enable new advanced applications, such as forming intentional islands (microgrids) for high-reliability applications and reducing fault level currents of DER.

In the past, designers used an application-specific power electronics approach to minimize the size, cost, and complexity of these systems. For example, an inverter used to connect a solar array with the utility grid was designed exactly for that purpose. It contained only the components and controls necessary for that application, and these were not compatible with any other renewable energy source.

There are several disadvantages to this approach. First, while the short-term advantage is that this is the least-cost option for the specific application, the longer-term disadvantage is that the narrow market opportunity for that specific application makes it nearly impossible to achieve the lower costs and improved reliability necessary for long term success. A device that is suitable for more technologies can be expected to have a lower overall cost and improved reliability because of higher production volumes. In addition, the application-specific approach has higher lifetime maintenance costs because of limited replacement parts and less experienced maintenance personnel.

Standardized electrical interfaces, connections, and communications can all help achieve a universal plug-and-play environment for interconnection. Standardization accommodates multi-functional interconnection systems that optimize generation, storage, and load, while providing ancillary services that benefit the energy customer and the utility grid. With standardized, cross-DER system capability, enabled by the advanced power electronics capabilities, it is possible to achieve near-universal functionality for load management and grid support for all DER systems.

### **Workshop**

On behalf of the California Energy Commission PIER Program, NREL organized an Advanced Power Electronics Interfaces for Distributed Energy Workshop that was held Aug. 24, 2006, in Sacramento, California. Forty-one representatives from industry, state and federal governments, and national laboratories attended.

The workshop provided a forum for industry stakeholders to share their knowledge and experience about technologies, manufacturing approaches, markets, and issues in power electronics for a range of distributed energy resources. It focused on the development of advanced power electronic interfaces for distributed energy applications and included

discussions of modular power electronics, component manufacturing, and power electronic applications.

The workshop was organized into four sessions. Each session included multiple presentations, and subsequent discussion periods allowed attendees to ask questions and share thoughts on power electronics issues. The topics included:

- Experience With Modular Power Electronics
- Advanced Concepts and Components
- Modular Power Electronics
- Power Electronics for Distributed Energy Applications.

Conclusions from the workshop were that there is a need for a standardized interface for power electronics and that scalability and modularity in power electronics are important. Other findings are that there is a:

- Need for power electronics to perform with high reliability and mean time between failure.
- Need to reduce the cost of power electronics components and address the increasing cost of current designs.
- Reluctance of industry to forfeit proprietary designs for a standardized interface and the threat/opportunity of commoditization.
- Need for longer warranties for power electronics products and improved certification scenarios and lower-cost certification methods.
- Need to plan for power electronics early in system designs to reduce costs and increase effectiveness.

The information collected from this workshop is a resource for organizations that plan to submit proposals in response to an upcoming Energy Commission PIER request for proposals for an advanced power electronic interface.

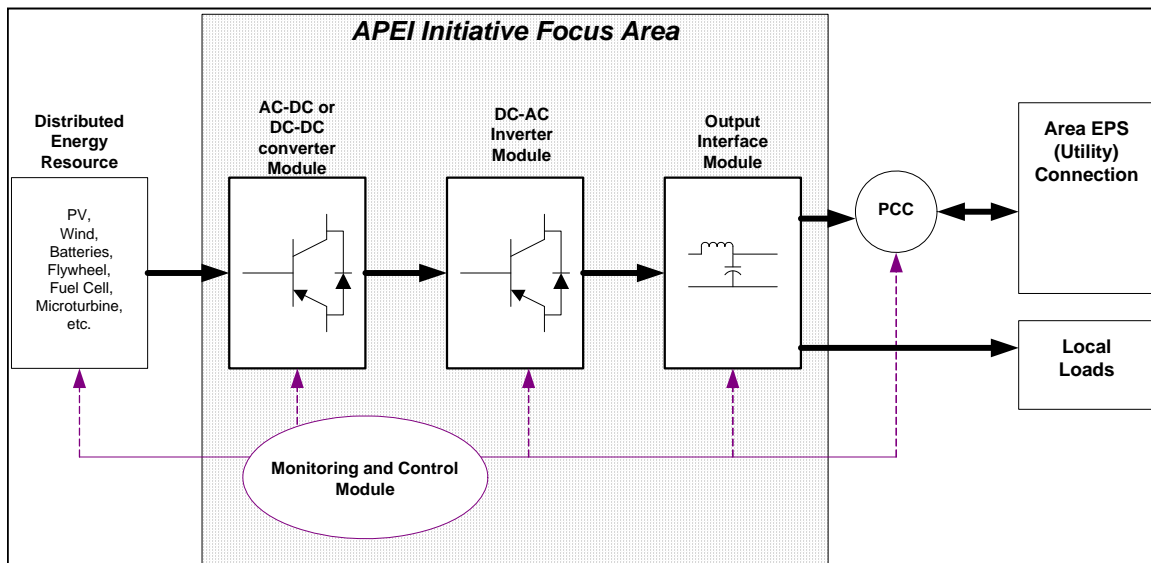
### ***3.4.3. Research and Analysis Conclusions and Recommendations***

The evaluation of the advanced power APEI resulted in a coordinated plan to develop modular architecture for standardized, highly integrated power electronics interconnection technologies for distributed energy resource platforms. The goal of this proposed plan is to improve and accelerate the use of DER technologies, to reduce costs for DER interconnections, and to develop high production volume modules. In order to achieve this goal, several needs were identified.

- The need for a standardized interface for power electronics.
- The importance of scalability and modularity in power electronics.
- The need for power electronics to perform with high reliability and mean time between failure.
- The need to reduce the cost of power electronics components and address the increasing cost of current designs.

- The reluctance of industry to forfeit proprietary designs for a standardized interface and the threat/opportunity of commoditization.
- The need for longer warranties for power electronics products and improved certification scenarios and lower-cost certification methods.
- The need to plan for power electronics early in system designs to reduce costs and increase effectiveness.

Based upon these results, researchers created a plan for a phased approach to developing the APEI. The APEI Initiative is envisioned as a six-year effort that uses a coordinated plan to develop a modular architecture for standardized, highly integrated, modularized power electronics interconnection technologies that will come as close as possible to “plug-and-play” both for distributed energy resource (DER) platforms and a wide variety of applications. This approach will reduce costs by creating a large market for core power electronics elements in the interface system. The combination of firmware, software, and/or hardware modularity will provide both an expansion capability and the flexibility to adapt to a variety of needs and applications.



**Figure 9. Diagram illustrating a modular power electronic interface approach**

Source: NREL

Figure 9 shows the various modules included in the initiative. These modules include a module that converts the energy from the DER to a suitable voltage and frequency to interface with an inverter module. The inverter module converts the DC power to grid-compatible AC power. The output interface module should include filtering and advanced controls that allow the interface to correctly connect to the utility grid. There is also a module that serves as a monitoring and control function for the entire system.

The APEI Initiative will identify where standardization can be used most advantageously to (1) streamline the development of components and systems so that all elements work together, (2) create scaleable DER modules that can interface with other modules from high-volume power electronics markets, (3) increase DER functionality including energy source optimization, load management, grid support, next generation grids, and planned islanding, (4) meet interconnection system requirements, and (5) foster improved DER interoperability, aggregation, and penetration. This will be accomplished through a combination of a directed R&D solicitation, modeling, and testing.

## **4.0 Conclusions and Recommendations**

### **4.1. Summary Conclusions**

#### ***4.1.1. Integrated Power Switch***

In summary, NPS developed a prototype integrated switch, demonstrating the concept of a modular and integrated approach to power electronic interface design. The switch met its defined goals, including meeting the applicable provisions of the IEEE 1547 standard, achieving a 30% or greater reduction in equipment costs compared to current solutions, and achieving a 50% or greater reduction in project engineering costs compared to current solutions.

#### ***4.1.2. Innovative Ratemaking for DER***

Through reviews of regulatory proceedings, existing tariffs, publications, and interviews, the researchers identified a number of approaches to standby and associated rates that deserve policy makers' attention if they are to promote cost-effective DER in their states. Implementing DER reduces consumer demand for grid-supplied energy, and DER systems can defer or avoid transmission and distribution investments. However, it is also important that all customers pay their share of the costs for the availability and reliability of grid power. In order to fairly implement DER-related tariffs, reliable analyses of the costs and benefits of on-site generation are needed. At the time of this study, completed in the fall of 2005, no such evaluation had been conducted. Analyses and modeling were also needed to examine the effects of DER equipment on distribution systems. These were accomplished as part of this project.

#### ***4.1.3. Verified Model to Evaluate the Effect of DER Systems Interconnected to a Distribution Circuit***

This research developed and validated modeling tools as part of the open access DEW software. These tools will enable utility protection engineers to evaluate the effects of unbalanced loading and voltage regulation for distribution circuits with operating and shutdown interconnected DER systems. Recommendations from this study are that system engineers conduct a three-phase, unbalanced power flow study, as the balanced model is inaccurate. The system should be modeled to include the specific locations where the DER system installation is planned. To use the models and obtain accurate results, the only measurements needed are the phase voltages and current taken at the source, regulators, capacitors, and DER system locations.

#### ***4.1.4. Research, Analysis, and Planning for DER Interconnection***

An advanced power electronic interface will require a coordinated plan in order to develop modular architecture for standardized, highly integrated power electronics interconnection technologies for DER platforms. The goal of the APEI Initiative is to improve and accelerate the use of DER technologies, to reduce costs for DER interconnections, and to develop high production volume modules. In order to achieve this goal, the interface must be standardized, be modular and scalable to different distributed energy resources, perform with high reliability and mean time between failures, provide longer warranties, have improved certification scenarios, and offer lower-cost certification methods.

## **4.2. Recommendations for Future Research**

### **4.2.1. Integrated Power Switch**

The DER switch program surveyed a range of requirements for grid interconnecting DG equipment. A semiconductor-based switch costs more than an electromechanical one, but it makes it possible to meet requirements for fast disconnection and power quality requirements. Several areas for improvement and additional work were identified and are listed below.

- More effort is needed in the development of calibration procedures and methods to improve measurement accuracy and tolerance levels for the DER switch to meet utility-grade relay standards. Integrating switch operation, protective relaying functions, and enterprise energy management into a single DSP helps achieve the reduction in equipment costs.
- While standard commercially available components helped achieve the reliability goals for the switch, more detailed tests and analysis would determine the exact reliability characteristics of this switch
- There are unique higher power quality goals for a grid interconnection device that uses semiconductor-based switches.
- Further testing of the DER switch can be used to verify the ability to detect and trip a wider range of grid events.
- Refined control algorithms should help achieve the Computer Business Equipment Manufacturers Association (CBEMA) curve requirements while minimizing nuisance trips.
- Automatic calibration procedures such as a floating point DSP platform can help mitigate some of the loss of accuracy related to fixed-point conversions and can be used to integrate more advanced control and protection algorithms.
- Further testing will enable detailed analysis of response of the switch to single-phase events. New designs should integrate switch operation and perform protective relaying functions and enterprise management to reduce overall costs.
- The accuracy of the relay functions can be improved by using more detailed calibration processes to compensate for sensor errors.
- The floating point DSP platforms can be used to integrate more advanced control and protection algorithms.
- Future versions of the DER switch should focus on cost reduction to make the technology competitive for a wider range of applications.

#### **4.2.2. *Tariff Options for Grid-Connected DER System***

Several tariff options and research topics were identified and are listed below:

- Identify the billing determinants that best reflect the costs incurred to serve DER customers.
- Determine to what extent established costing and traditional ratemaking principles and precedents are applicable when designing rates for DER customers. Research targeted at understanding specific DER installations and interaction with the electrical grid and utility systems will assist in determining if established costing principles can be applied and substantiate appropriate changes and innovation in ratemaking for DER.
- Pursue more detailed analyses of specific rate structures, using well-defined criteria for judgment. These criteria could include economic efficiency, minimization of cost shifting, consistency with cost causation principles, consistency with state policy goals (including energy, environmental, and economic), and acceptability to stakeholders.
- Conduct probabilistic analysis of when DG will be on, how it will be used, and how multiple DG installations on a portion of the distribution system affect the system and how this information could be used to define rate structures.
- Develop methods to incorporate DG into distribution system planning.
- Develop performance objectives and design rates that encourage customers to operate their DG as much as possible.
- Align utility revenue collection incentives with public policy goals.
- Develop policy goals with explicit exemptions and incentives in support of state or national goals.
- Examine revenue-cap performance-based regulation with volumetric rates. Such regulation could ensure distribution companies fixed revenues while providing customers with incentives to modify their consumption.
- Tie rate treatment to an emissions or efficiency threshold.
- Evaluate the intrinsic benefits of DER for off-peak demand and peak supply to define a rate while capturing these unrecognized DER benefits.

#### **4.2.3. *Verified Model to Evaluate the Effect of DER Systems Interconnected to a Distribution Circuit***

There are several topics for additional evaluation for modeling the impacts of DER equipment on a distribution system, beyond the voltage regulation effects covered in this report. These are listed below:

- The effects of DER equipment on system protection systems must be further evaluated.
- A real-time optimal control of the distributed generation to optimize generator voltage control conditions, including the control of the substation transformer LTC, the bi-

directional voltage regulators, and the switched capacitors, needs to be modeled and evaluated.

#### **4.2.4. Research, Analysis, and Planning for DER Interconnection**

The primary recommendation from this task is to formulate the rationale for an Advanced Power Electronic Interface Initiative. The study showed that research is needed on three basic industry problems in the area of power electronic interfaces:

- Cost – There exists a need to reduce cost of power electronic interface for DER. Power electronics are part of key DER technologies and represent a significant portion of the capital costs.
- Reliability – There exists a need to improve power electronic interface reliability from the typical 1-5 year warranty to 10-20 years (to match warranties on DER equipment).
- Functionality – Additional functionality (increased power quality, voltage/VAR support, seamless backup power, etc.) can be included with development of advanced power electronic interfaces.

The APEI Initiative is designed to develop a modular architecture for power electronics interconnection technologies that will come as close as possible to “plug-and-play” for DER platforms. The APEI Initiative will evaluate the current cost of power electronics technologies and conduct research on how to lower costs and increase functionality of the power electronic interfaces. This will represent a significant advancement for the distributed energy technology base.

### **4.3. Benefits to California**

The benefits to California are numerous and significant. The research developed processes, standards, and technology for the purposes of integrating DER into California’s electrical distribution system and marketplace. These activities support the goals of the *Energy Action Plan* and the California Distributed Generation Strategic Plan to use DER technologies to enhance the cost effectiveness, reliability, power quality, security, and environmental friendliness of the California and U.S. electric power system. These goals are consistent with the overall PIER Program objectives, which include:

- Improve energy cost/value of California’s electricity.
- Improve the reliability/quality of California’s electricity.
- Improve the safety of California’s electricity.

The Universal Interconnect Devices task demonstrated a flexible DER utility interface system that successfully met the performance requirements for costs and grid interconnection specifications. In the Innovative Ratemaking task, rate and tariff structures were proposed that would allow DER to be compensated for the full range of benefits it can provide consumers, such as electricity cost reduction, power system expansion deferral, and transmission and distribution loss reduction. Under the Modeling and Testing of Effects of Unbalanced Loading

task, a model was developed using open access software that will allow a utility to evaluate the impacts of DER equipment on a distribution circuit, thereby allaying some utility concerns and improving the understanding of how these systems interact. As part of the Modeling, Research, Analysis and Planning task, California will see future benefits from increased utility and lower costs of interconnecting DER systems with the electric power system. Combined, these research results have provided material advancements toward reducing the costs and improving the reliability of electric power in California.



## 5.0 References

Title: *Advanced Power Electronics Interfaces for Distributed Energy Workshop Summary*

Energy Commission Report #: CEC-500-2006-038

NREL Report #: NREL/BK-581-40480

Title: *Flexible DER Utility Interface System: Final Report, September 2004 - May 2006*

Energy Commission Report #: TBD

NREL Report #: NREL/TP-560-39876

Title: *Modeling and Testing of Unbalanced Loading and Voltage Regulation*

Energy Commission Report #: TBD

NREL Report #: NREL/SR-581-41805.

Title: *Rate Structures for Customers With Onsite Generation: Practice and Innovation*

Energy Commission Report #: CEC-500-2006-038

NREL Report #: NREL/SR-560-39142



## 6.0 Glossary

Term	Definition
ANSI	American National Standards Institute
BOM	balance of materials
CBEMA/ITIC	Computer Business Equipment Manufacturers Association/Information Technology Information Council
DR or DER	distributed energy resources
DEW	Distribution Engineering Workstation
DG	distributed generation
DOE	United States Department of Energy
DTE	DTE Energy
IEEE	Institute of Electrical and Electronics Engineers, Inc.
I/O	input/output
KW	kilowatt
KVAr	kilovars
MTBF	mean time between failure
MTTF	mean time to failure
MTTR	mean time to repair
MW	megawatt
MVA	megavolt-amperes
NEPA	National Environmental Policy Act
Northern	Northern Power Systems
NREL	National Renewable Energy Laboratory or Facility Operator
NARUC	National Association of Regulatory Utility Commissioners
PIER	Public Interest Energy Research
Q	resonant test circuit quality factor
RD & D	research, development, and demonstration
RTU	remote terminal unit
SCC21	IEEE Standards Coordinating Committee 21 Fuel Cells, Photovoltaic, Dispersed Generation, and Energy Storage
SEMI	Semiconductor Equipment and Materials International
Synapse	Synapse Energy Economics
UL	Underwriters Laboratory
VARS	volt amperes reactive